FINAL
Technology Options Memo
Honolulu High-Capacity Transit Corridor Project

April 27, 2006

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City and County of Honolulu

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Executive Summary

This report presents an assessment of alternative transit technologies for the Honolulu High-Capacity Transit Corridor (HHCTC) Project. This assessment identifies potential transit technology categories and assesses those technologies against a set of Corridor-specific evaluation criteria. This assessment provides information for decision makers and supports subsequent analysis and engineering activities.

It is anticipated that the full range of transit service types could apply to the HHCTC, from Low Speed Mixed Traffic all the way up to High Speed Exclusive Right-of-Way (ROW). For example, at-grade mixed flow traffic service might be applicable in the Kapolei area or in portions of downtown as an alignment transition from elevated to subsurface. Similarly, the desire to not "lose any traffic lanes" in certain areas would necessitate construction of new facilities in order to operate an exclusive right-of-way service. Therefore, the transit technologies were evaluated against each type of service that they typically operate within.

The findings of this technology assessment will combine with findings of a parallel alignment analysis to form final alternatives (technology/alignment pairings) to be carried forward for further analysis and screening. Each alternative will have a line haul component and feeder components. Technologies on a line haul component could operate in; 1) mixed traffic with automobiles, 2) an exclusive ROW, or 3) segments of both mixed traffic and exclusive ROW. A managed lane operating environment, which enables higher speed operations in limited mixed traffic, was also considered as a potential line haul component. Technologies on a feeder component could operate in mixed traffic or exclusive ROW but probably not both due to the shorter distance of feeder components compared to line haul. Hence, technologies are assessed for their ability to provide mixed traffic and/or exclusive ROW service in either a feeder or line haul component of an alternative.

Initial Screening of Technology Categories

A full range of potential transit technology categories were considered and passed through an initial screening:

- Conventional Bus – Standard 40 foot single unit and 60 foot articulated transit buses.
- Guided Bus – Buses with guidance mechanisms for precision docking or reduced guideway width operations.
- Light Rail Transit (LRT) – Steel rail-based vehicles that can operate in mixed traffic or on exclusive guideways. Includes streetcar trams, standard light rail and light rail diesel multiple units (DMU).
- Personal Rapid Transit (PRT) – A technology that uses small, automated vehicles on exclusive guideways that provide service between a passenger's origin and destination.

- Emerging Technologies – Transit technologies that are still in the developmental stages.
- People Mover – Automated vehicles that typically operate on rubber tires on an exclusive guideway.
- Monorail – Vehicles that travel along an elevated guideway beam on rubber tires. Straddle beam types appear to wrap around the guideway beam.
- Maglev – A technology that uses magnetic force to support the vehicle above guide rails and linear induction motors to propel them.
- Rapid Rail Transit – Large, fast steel rail-based vehicles that can be combined into trains of up to ten cars.
- Commuter Rail – A steel rail-based technology category with large vehicles such as a locomotive-coach combination or single unit DMUs.
- Ferries - A ship-based technology category that provides point-to-point waterborne transit service for locations proximate to bodies of water.

These technology categories are not all appropriate for initial consideration for the HHCTC Project. An initial screening process identified "fatal flaws" for some technology categories when assessed within the HHCTC Project context. These categories were then eliminated prior to detailed analysis. The screening criteria considered the technology's technical maturity, line capacity and speed capability, station/stop spacing requirements, and its ability to provide access to the key activity centers in the Corridor.

The four transit technology categories that did not make the list as a potential technology for the HHCTC Project are:

Personal Rapid Transit – Personal Rapid Transit was eliminated due to insufficient cruise speed and limited technical maturity. Current technologies in development have cruise speeds of 19 to 31 mph. There are no service-proven PRT systems on the market today capable of meeting the line haul capacity requirements.

Commuter Rail – Commuter Rail was eliminated because it is inappropriate for short station spacing envisioned for portions of the Corridor. In addition, the lack of existing rail line(s) that link the corridor's key activity centers eliminates one of this technology category's inherent cost advantages.

Emerging Technologies – Emerging technologies were eliminated from consideration in this alternatives study because they are lacking technical maturity. Individually, the various technologies generally fit into one of the initially identified technology categories, so if they are developed further and are no longer in research and development, they might be considered during later stages of project implementation.

Ferry –Waterborne ferries were eliminated from consideration in this study as the primary mode for the Corridor as it does not serve the many origins and destinations between the boarding points well including the Corridor's key activity centers. This technology category can supplement transportation services in the corridor, but is not applicable as the primary transit linkage.

Transit Technology Assessment

The remaining seven technology categories were then assessed against criteria including Technical Maturity, Line Capacity, Performance, Maneuverability, Costs, Environmental, Safety, Supplier Competition, and Accessibility. Within several of the technology categories, specific sub-categories of technologies were assessed. For example, LRT includes Streetcar Trams, Light Rail Vehicles (LRV), and articulated DMU's configured for an LRT application.

Table 1 provides a summary of the findings from the technology assessment. Detailed discussion of the findings for each of the technologies within each type of service is provided in Chapter 3 of the report.

General findings from the HHCTC technology assessment can also be summarized as follows:

- No single technology emerged as far superior to others within any of the Types of Service.
- A number of technologies are found to be well suited for each of the Types of Service.
- For the two Mixed Traffic types of service, the Standard Conventional Bus, Articulated Conventional Bus, and the Light Rail Vehicle scored highest and are recommended for inclusion in the alternatives analysis. The Conventional Bus technologies are assumed for Managed Lane service and the Light Rail is assumed for fixed guideway service.
- For the two Exclusive ROW types of service, the Light Rail Vehicle, People Mover, Monorail, and Rapid Rail Vehicle technologies scored well and are recommended for inclusion in the alternatives analysis. The Maglev, which scored moderately, could also be considered for some forms of Exclusive ROW operations. Conventional bus and guided bus technologies are not recommended for exclusive ROW operations (other than managed lane applications) due to the physical constraints of constructing busways throughout the length of the corridor.
- For the shorter Feeder components, the Conventional Bus, Articulated Bus, Streetcar Tram, People Mover and Monorail are recommended for inclusion in the alternatives analysis.

These findings will be incorporated into the overall Alternative Screening Process for the HHCTC Project to help define the recommended list of alternatives

Table 1. Summary of Technology Screening

Technology	Advantages	Disadvantages	Recommendation			
			Feeder	Managed Lane	Line Haul	
					Mixed	Excl. ROW
Conventional Bus - Singe Unit (40')	- Good maneuverability - Low cost for at-grade - Good technical maturity - Short implement time	- Low line capacity in mixed traffic - Poor performance in mixed traffic - Poor safety in mixed traffic - Moderate environment	R	R	R	D[1]
Conventional Bus - Articulated (60')	- Good maneuverability - Low cost for at-grade - Good technical maturity - Short implement time	- Poor performance in mixed traffic - Poor safety in mixed traffic - Moderate environment	R	R	R	D[1]
Guided Bus	- Good maneuverability	- Supplier competition - Low line capacity	D	R	R	D[1]
Streetcar Tram	- Good environmental - Low cost for at-grade	- Supplier competition - Poor performance - Low line capacity	R	NA	D	D
Light Rail Vehicle	- Good performance - Low cost for at-grade - Supplier competition - Can operate all types of transit service	- Moderate line capacity in mixed traffic - Poor Safety - Maneuverability	D	NA	R	R
Light Rail Deisel Multiple Unit (DMU)	- Accessibility	- Moderate maturity - Poor performance - Maneuverability - Moderate environment	D	NA	D	D
People Mover	- Accessibility - High line capacity - Good safety & maturity	- High cost - Lower top speed - Maneuverability	R	NA	D	R
Monorail - Medium and Large	- Good safety & access - High line capacity	- High cost – low supply - Poor maneuverability	R	NA	D	R
Maglev	- High line capacity - Good environmental - Good safety	- High cost - Supplier competition - Poor technical maturity	D	NA	D	R
Rapid Transit - Medium and Large	- Good technical maturity - High passenger capacity - Good environmental - Good performance - Good safety and access	- Moderately high cost - Moderate maneuverability	D	NA	D	R

Legend: R = Retain for Alternatives Analysis D = Drop NA= Not Applicable

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[1] There are many successful examples of Conventional Bus and Guided Bus operating in exclusive ROW such as busways; however, due to the physical constraints of constructing separate bus ROW throughout this particular study corridor, this option was dropped from further consideration. Note that the managed lane option for buses provides many of the same benefits as exclusive ROWs.

Chapter 1 Introduction

This report presents an assessment of alternative transit technologies for the Honolulu High-Capacity Transit Corridor (the Corridor). This assessment determines the applicable types of transit service for the Corridor, identifies potential transit technology categories, and screens those technologies against a set of Corridor-specific evaluation criteria. This assessment provides information for decision makers and subsequent analysis and engineering activities.

Concurrent to this technology assessment, a screening of alignment options within the Corridor is being conducted. Once the two separate screening activities are complete, the remaining technology and alignment options will be carried forward into more detailed analysis.

Report Organization

Following this Introduction, Chapter 2 provides an initial screening and description of the range of transit technologies and applicable types of transit service. Chapter 3 presents the transit technology assessment including the assessment criteria used to compare the technologies and the assessment results. Chapter 4 presents a discussion on interfaces and integration of the line haul, feeder, and local transit services in the corridor. Appendix A provides a compendium with more detailed descriptions for those transit technologies that remain after the initial screening.

Project Background

The City and County of Honolulu (City) initiated a study of high-capacity transit service, the Honolulu High-Capacity Transit Corridor (HHCTC) Project, to improve person-mobility within its primary corridor between Kapolei and the University of Hawaii at Manoa (UH Manoa). The Kapolei to UH Manoa corridor contains the vast share of the total travel occurring on the island of Oahu. Existing transportation infrastructure in this corridor is overburdened in handling current levels of travel demand. Travelers experience substantial traffic congestion and delay at most times of the day on weekdays and weekends. These delays are expected to become worse over time.

Both rail transit and bus-based transit options are being considered in the study. The resulting Alternatives Analysis (AA) will provide the City Council with information to select a locally preferred alternative (LPA) for which federal funds will be sought for implementation.

Chapter 2 Initial Screening of Technologies

This chapter describes potential transit technologies and types of service that could be applicable to the Corridor. The chapter begins with an overview of the full range of transit technology categories and transit service types considered. The technology categories are then screened against a set of initial screening criteria. The chapter concludes with a summary of the typical operational characteristics for the short-listed transit technology categories as they apply to each type of transit service. The short-listed technologies are then assessed in more detail in Chapter 3.

Overview of Transit Technology Categories Considered

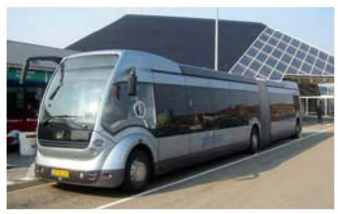
Technology categories are used at this screening level of analysis. Within each category selected for further analysis, specific transit vehicle technologies will be assessed. The range of technology categories initially considered includes land- and water-based categories.

Land-Based Technology Categories

Conventional Bus

This technology category consists of conventional buses that are single units 40 feet in length (i.e., standard buses) or an articulated vehicle 60 feet in length. A bus provides its own power from an on-board power source (such as a diesel engine or diesel-electric hybrid) or obtains electric power from an overhead wire distribution system (OWDS) as a trolleybus.

Guided Bus



The guided bus technology category is similar to a conventional standard or articulated bus that features provisions for operating with guidance for precision docking or reduced guideway width operations. Examples range in length from 40 to 80 feet. Guidance can be provided in a variety of ways including a slot in the pavement, side guidance, embedded magnets, or stripes on the pavement.

Light Rail Transit (LRT)

This steel rail-based technology category has 60- to 90-foot long vehicles that can be combined into multi-vehicle trains. These vehicles have articulation to improve maneuverability. Versions of this technology that have low floors, are sometimes narrower, and have shorter sections between articulations are termed modern Streetcar

Trams. Power is usually obtained from an OSWD (required for mixed traffic operations), but third rail applications also exist. Onboard diesel-electric power plants also exist on Diesel Multiple Units (DMUs) configured for light-rail-type applications. Historic, single-unit streetcars are not considered for the line haul function in the Corridor due to limited speed and passenger capacity.

Personal Rapid Transit (PRT)

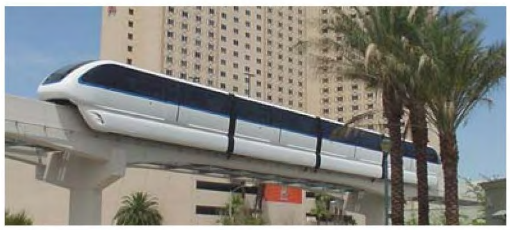
Personal Rapid Transit (PRT) is a technology category that is intended to operate in a network system directly between a passenger's origin and destination with short headways between vehicles. The technology typically uses a large number of automated, small vehicles (two to ten passengers) on an exclusive, separated guideway. One small system is operating today, the Morgantown PRT, and several other concepts are under development.

People Mover

This technology category has a wide range of vehicle types. For the Honolulu application, however, only the larger sized versions of this category are considered. This type uses cars about 36 to 42 feet in length that typically operate on rubber tires in an automatic, driverless mode. They can be combined into short, multi-vehicle trains. Power is obtained from a third rail.

Monorail

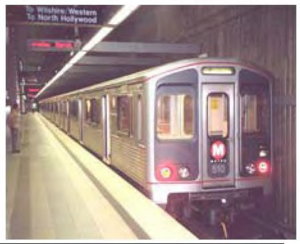
This technology category features trains that straddle an elevated guideway beam with rubber load and guide tires running along the beam beneath the cars. Both large and medium size versions of these trains exist. Large versions feature wider, longer, and taller vehicles. Power is obtained from a third rail. Suspended monorails are not considered here since the associated evacuation procedures are problematic because an emergency walkway cannot be built easily with the supporting guideway above the vehicle roof.



Magnetic Levitation (Maglev)

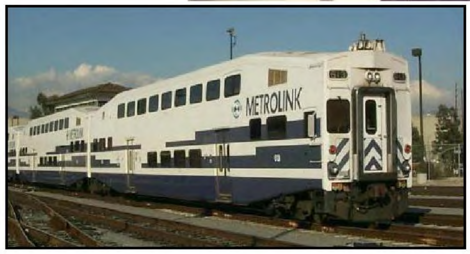
This technology uses magnetic force to support the vehicle above guide rails and linear induction motors to propel them. Power is obtained from a third rail. As related to other maglev applications, the technology under consideration in this study is "low speed maglev" which has a top speed of about 62 miles per hour.

Rapid Rail Transit



This steel rail-based technology category features vehicles 45 to 75 feet in length, without articulations, that can be combined into trains of up to ten cars operating faster than 62 mph. Power is usually obtained from a third rail.

Commuter Rail



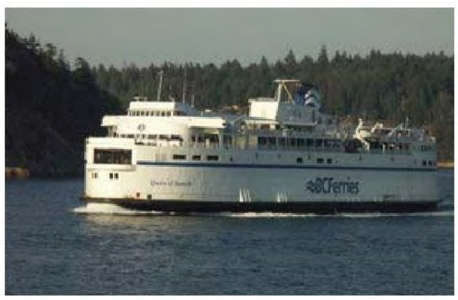
This steel rail-based technology category often uses trains consisting of one or more non-powered passenger cars pulled by a locomotive. The locomotive is typically a diesel-electric. Single-unit DMUs (non-articulated) used in commuter rail applications are substantially heavier than DMU's configured for a light rail application to comply with the Federal Railroad Administration's requirements for crash worthiness. Station spacing is typically four or more miles apart. The trains are compatible with freight rail trains (track gauge) and often operate in mixed rail traffic over track owned by others.

Emerging Technologies

This technology category includes technology concepts that are still in the developmental stages as well as existing technologies that are unique in nature and do not fit into the other technology categories. These technologies include the Futrex monorail, Cybertran Group Rapid Transit, Aeromovel, and Aerobus suspended monorail.

Water-Based Technology Categories

Ferry



This ship-based technology category provides point-to-point waterborne transit service for locations proximate to bodies of water. It is typically applied in locations of special needs or constraints, such as large bodies of water that are not well served by traditional bus or rail systems. Specific waterborne technologies within the Ferry Category include Mono-hull Vessels, Dual-hull Vessels, and Hydrofoils. Mono-hull vessels are most common and operate at slower speeds with vessels about 150 feet in length. Dual-hull vessels, also known as Catamarans, are typically built of lighter weight materials with 150- to 200-foot vessels operating at moderate speeds. Hydrofoils travel above the water surface on metal struts that allow higher operating speeds. Hydrofoil vessels are relatively expensive and require deep channels.

Transit Service Types

The transportation system in the Corridor could include a variety of transit services to meet travelers' needs from origin to destination. As applied to this corridor, the types of transit service can be categorized as:

- Low speed in mixed traffic – Transit vehicles travel in or directly adjacent to roadway lanes and are subject to frequent interactions with automobile and truck traffic resulting in significant delays. This type of service might receive priority treatment at intersections. Transit stops are typically closely spaced (less than 0.3 miles), which also restricts overall average travel speed.
- Low speed in limited mixed traffic – Transit vehicles travel in right-of-way typically separated from, but at the same grade as, roadway lanes. Transit vehicles are usually provided with some priority treatments at intersections, but interactions and moderate delays still occur. Transit stops are typically relatively closely to moderately spaced (less than 0.5 miles).
- Moderate speed in exclusive right-of-way – Transit vehicles travel in dedicated right-of-ways. Roadway crossings are either grade-separated or at-grade with priority usually given to the transit vehicle to minimize delays. Transit stops are moderately spaced (0.5 to 1.0 miles), which permits average travel speeds to be at moderate levels (up to about 35 mph).
- High speed in exclusive right-of-way – Transit vehicles travel in dedicated right of ways. Roadway crossings are primarily grade-separated but some controlled at-grade crossings are possible with the transit vehicle always given priority. Transit stops are widely spaced (more than 1.0 miles) permitting relatively high overall average travel speeds (up to about 45 mph).

These various types of transit services are necessary to fit within the Corridor's existing physical opportunities and constraints and serve the multiple trip components for travel in the Corridor. The corridor's existing opportunities and constraints help to define the type of transit service provided. For example, while some portions of the corridor have space for at-grade or elevated, exclusive facilities, other locations may benefit from at-grade, mixed traffic applications to reduce impacts or increase access to the transit service. Chapter 4 provides a discussion of trip components and the integration of an overall transit system in the corridor

A variety of transit technologies can potentially be applied to each type of transit service as shown in Table 2. The selection of the appropriate technology category to be used in alternatives will be a function of finding the best "fit" for the specific application. This determination will consider the specific requirements of each alternative concept.

Table 2. Potential Transit Technology Category Applications

Type of Transit Service	Conventional Bus	Guided Bus	Light Rail Transit	Personal Rapid Transit	Emerging Technologies	People Mover	Monorail	Maglev	Rapid Rail Transit	Commuter Rail	Ferries
	Transit Technology Category										
Low Speed in Mixed Traffic	●	●	●	×	×	×	×	×	×	×	×
Low/Moderate Speed, Limited Mixed Traffic	●	●	●	×	×	×	×	×	×	×	×
Moderate Speed, Exclusive ROW	●	●	●	●	●	●	●	●	●	O	●
High Speed, Exclusive ROW	● [1]	● [1]	●	×	×	O	O	●	●	●	×

Source: Lea+Elliott, Inc., October 2005

Legend: ● = Primary Application; O = Secondary Application; × = Not Applicable

[1] While Conventional Bus and Guided Bus are capable of operating in high speed, exclusive ROW, they are not being considered for that function in this analysis due to the physical constraints of constructing a Busway throughout the corridor.

Technology Category Screening

The technology categories listed in Table 2 are not all appropriate for initial consideration for the HHCTC Project. The examination of high capacity transit service in the Kapolei to UH Manoa Corridor is to focus on achieving regional transportation goals and objectives, including goals to do the following:

- Improve corridor mobility
- Encourage patterns of smart growth and economic development
- Find cost effective solutions; and
- Minimize community and environmental impacts.

These goals help to define both an initial screening criteria for the range of technology categories initially under consideration as well as the subsequent, more detailed screening criteria applied to specific technologies within the remaining technology categories. The initial screening process identifies “fatal flaws” of a technology category in this context that warrant elimination of the category prior to any detailed analysis being performed.

Initial Screening Criteria

The technology categories were selected based on initial screening criteria that considered capabilities and technical maturity appropriate for the HHCTC Project. These criteria were:

- Technical Maturity – The technology category should be beyond the prototype development stages and use demonstrated, service proven technologies to increase project cost certainty and reduce schedule risk.
- Line Capacity – The technology category should be capable of a moderately high minimum line capacity of 3,000 to 5,000 passengers per hour per direction (pphpd) to meet the preliminarily projected low end of passenger ridership estimates.
- Cruise Speeds – The technology category should have technologies that are capable of maintaining cruise speeds of at least 43 to 62 mph for effective line haul operations within the 23-mile corridor.
- Station/Stop Spacing – Since the corridor includes several different activity centers, the technology category should be appropriate for transit services with both long station/stop spacing (1 mile or more in the outlying areas) and relatively short station stop spacing (0.25 to 0.5 miles) in the urban core areas. In addition, the technology category should be able to serve destinations through the length of the corridor.
- Activity Center Access – The technology category should be able to access the key activity centers in the Corridor.

Eliminated Transit Technology Categories

Several transit technology categories did not make the list as a potential technology for the HHCTC Project. These include:

Personal Rapid Transit – Personal Rapid Transit was eliminated due to insufficient cruise speed, limited technical maturity and low line capacity. Current technologies in development have cruise speeds of 19 to 31 mph. There are no service-proven PRT systems on the market today, especially any that are capable of meeting the line haul capacity requirements.

Commuter Rail – Commuter Rail was eliminated because it is inappropriate for close station spacing envisioned for portions of the Corridor. In addition, the lack of existing rail line(s) that link the corridor's key activity centers eliminates one of this technology category's inherent cost advantages.

Emerging Technologies – Emerging technologies were eliminated from consideration in this alternatives study because they are lacking technical maturity. Individually, the various technologies generally fit into one of the initially identified technology categories, so if they are developed further and are no longer in research and development, they might be considered during later stages of project implementation.

Ferry –Ferries were eliminated from consideration in this study as the primary mode for the Corridor as it does not serve the many origins and destinations between the boarding points well including the Corridor's key activity centers. This technology category can supplement transportation services in the corridor, but is not applicable as the primary transit linkage.

Remaining Technology Categories and Their Characteristics

Seven transit technology categories were deemed appropriate for further evaluation following the initial screening:

- Conventional Bus
- Guided Bus
- Light Rail Transit
- People Mover
- Monorail
- Maglev
- Rapid Rail Transit.

Table 3 lists typical characteristics for the seven remaining transit technology categories for the HHCTC Project. The characteristics are shown for each applicable technology category for the four different types of transit service and provide an indication of how each technology category functions in a particular type of transit service. This table includes a summary description of these categories highlighting their distinguishing characteristics including:

- Demand Volume Served – the typical hourly volume of passengers that can be moved in the peak hour in one direction.
- Average Travel Speed – the typical overall average speed, beginning to end, for a trip on the technology category including dwell times, vehicle running times, and delays.
- Transit Stop Spacing – the typical distance between boarding/alighting locations such as bus stops or train stations.

Appendix A provides additional details on technologies within each of the remaining technology categories.

Each technology category provides slightly different characteristics within a given transit service type. Individual technology categories also have varying performance in different transit service environments. For example, Light Rail Transit vehicles can accommodate different maximum demand volume levels for the low and moderate speed types of service. This is primarily because shorter trains are often needed for low-speed mixed-traffic operations due to street block length limitations.

Table 3 also shows that as station spacing increases, the acceleration and maximum speed capabilities of technologies become more important determinants of overall average travel speeds. With closely spaced stops, the categories have similar speeds since the speed is primarily dictated by dwell times and, for non-exclusive right of ways, traffic interference. Transit service types with larger stop spacing show a greater correlation between overall average speeds and maximum technology cruise speeds.

Table 3. Transit Technology Category Typical Characteristics

Type of Service	Technology Category	Typical Directional Demand Volume Served[1]	Typical Average Travel Speed[2]	Typical Stop Spacing
Low Speed, Mixed Traffic	Conventional Bus	1400-2200 pph	5-12 mph	0.1-0.3 mi
	Guided Bus	2200-3000 pph		
	Light Rail Transit	1900-5900 pph		
Low Speed in Limited Mixed Traffic	Conventional Bus	1400-2200 pph	10-17 mph	0.2-0.5 mi
	Guided Bus	2200-3000 pph		
	Light Rail Transit	1900-8900 pph		
Moderate Speed in Exclusive ROW	Conventional Bus[3]	1400-2200 pph	15-25 mph	0.2-1.0 mi
	Guided Bus[3]	2200-3000 pph	17-30 mph	0.5-1.0 mi
	Light Rail Transit	5800-17800 pph	20-35 mph	
	People Mover	5900-11800 pph	15-30 mph	0.2-1.0 mi
	Monorail	7000-22100 pph		
	Maglev	9300-18600 pph	20-35 mph	0.5-1.0 mi
	Rapid Rail Transit	8200-32600 pph		
High Speed in Exclusive ROW	Conventional Bus[3]	1400-2200 pph	20-35 mph	1.0-2.5 mi
	Guided Bus[3]	2200-3000 pph	20-30 mph	
	Light Rail Transit	5800-17800 pph	20-40 mph	
	People Mover	5900-11800 pph	20-35 mph	
	Monorail	7000-22100 pph		
	Maglev	9300-18600 pph	20-45 mph	
	Rapid Rail Transit	8200-32600 pph		

Source: Lea+Elliott, Inc, October 2005

Legend: pph = passengers per hour; mph = miles per hour; mi = miles; ROW = right of way.

Notes:

[1] The demand volumes served shown represent volumes that can be served by a single route. Higher demand volumes can be served in trunk line sections where multiple routes overlap.

[2] Speeds shown are overall average travel speeds including dwell times and delays due to mixed traffic operation, where applicable.

[3] Demand volumes provided are for a single route. The "trunk-line" portion of Busways and Managed Lanes typically carry more than one route and therefore can serve higher demand volumes. The higher volumes would require off-line stops and multiple overlapping routes.

Chapter 3 Transit Technology Assessment

This chapter describes the assessment of the specific technologies within the technology categories that remain under consideration following the initial screening of technology categories in Chapter 2. Specific technologies are assessed against a list of detailed screening criteria developed for the HHCTC Project. These criteria are defined in the following section. The technology assessment methodology is then described and, finally, the results of the assessment are provided.

Technology Assessment Criteria

The current definition of alternatives for the Corridor includes alignments that potentially include elevated, at-grade, and tunnel sections, as well as all four types of transit service. Accordingly, the transit technologies under consideration are screened within the context of each of the four types of transit service that a technology typically serves. The technology screening criteria included Technical Maturity, Line Capacity, Performance, Maneuverability, Costs, Environmental, Safety, Supplier Competition, and Accessibility. Some of these criteria were also applied in the initial screening where a low score would indicate a fatal flaw. In this secondary technology screening, the resulting assessment grade will help to differentiate among the short-listed technology categories and the specific technologies within each category. The assessment criteria are:

- Technical Maturity – The technologies to be selected for combining with specific alignments must minimize risk from technical and schedule perspectives. Technical maturity is measured in terms of operating service years, number of operating applications, and reliability of operating systems.
- Line Capacity – Selected technologies must have the capacity to accommodate the travel demand for the planning horizon of year 2030. At this stage of the project a detailed travel demand estimate has not been produced, however from earlier work in the Corridor it is assumed that a minimum line haul demand between 3,000 and 5,000 persons per hour per peak direction (pphpd) will have to be accommodated by the technology. Capacity will be measured for a technology's minimum and maximum train length (for those that can be entrained).
- Performance – Due to the distances between various activity centers being connected by the project, technologies should achieve relatively fast travel times. Higher operating speeds will result in faster travel times that promote system use.
- Maneuverability – Technologies must be able to physically operate within the Corridor. Maneuverability relates to the right-of-way requirements for a technology given its performance capabilities and constraints with regard to the geometry of proposed alignments. This is measured in terms of a technology's achievable minimum curve radius for the horizontal alignment and by the maximum grade for the vertical alignment.

- Costs / Affordability – The selected technologies should be cost effective given the type of service (mixed traffic vs. exclusive ROW) they provide. Costs are considered in terms of annualized capital costs, O&M costs, cost variability (technologies ability to be at-grade as well as elevated) and the cost of extension (supplier competition for system extensions).
- Environmental – The resulting exhaust and noise emissions generated by the technology should be acceptable within the Corridor.
- Safety – Technologies must meet local and national life/safety requirements. The transit operations should be inherently safe or the design of the system can accommodate safety concerns in a cost-effective manner. This is measured in terms of right of way exclusivity.
- Supplier Competition – A sufficient number of suppliers of the technology need to be available to foster price competition on the project to obtain a cost effective system.
- Implementation Time – This criterion considers the relative time for planning, design, permitting/funding and construction of the system.
- Accessibility – Selected technologies must comply with Americans with Disabilities Act (ADA) requirements. Vehicle boarding ease is another measure within this criterion and considers whether "level-boarding" occurs with a given technology.

Technology Assessment Methodology

The remaining technology categories were assessed in terms of the evaluation criteria described above and within each of their applicable types of transit service. Within several of the technology categories, specific sub-categories of technologies were assessed. For example, LRT includes Streetcar Trams, Light Rail Vehicles (LRV), and articulated DMU's configured for an LRT application. Each criterion is given a similar level of importance or "weight". Assessments range from a low grade of "Fail", indicating the technology might potentially be eliminated from further consideration, up to a high grade of "Excellent". Five assessment levels are used: Excellent, Good, Moderate, Poor and Fail.

Technology Assessment Results

Table 4 presents the results of the technology evaluation. The resulting criterion grades for each technology are provided graphically for each type of service, from a top grade of "excellent" (●) to a low grade of "fail" (○). These grades were derived from numerical scores, where a technology could score as high as ten (excellent) and as low as zero (fail) for a given criterion. With a total of ten evaluation criterion, a maximum score of 100 was possible. Total scores for each technology are provided in the right-most column of Table 4 below.

Table 4. Summary of the Technology Assessment by Transit Service Application

Type of Service	Technology	Technical Maturity	Line Capacity	Performance	Maneuverability	Cost / Affordability	Environmental	Safety	Supplier Competition	Implementation Time	Accessibility	Total Score (0-100)
Low Speed, Mixed Traffic	Conventional Bus - Standard 40’	●	◔	◑	●	●	◑	◔	●	●	◑	**68**
	Conventional Bus - Articulated 60’	●	◔	◑	●	●	◑	◔	●	●	◑	**70**
	Guided Bus	◑	◔	◑	●	◕	◑	◔	◑	◕	◕	**59**
	Streetcar Tram	◑	◑	◑	●	◕	◕	◔	◕	◑	◕	**57**
	Light Rail Vehicle	●	◕	◑	●	◕	◕	◔	●	◑	◕	**67**
Low Speed in Limited Mixed Traffic	Conventional Bus - Standard 40’	●	◔	◑	●	●	◑	◑	●	●	◑	**74**
	Conventional Bus - Articulated 60’	●	◑	◑	●	●	◑	◑	●	●	◑	**76**
	Guided Bus	◑	◔	◑	●	◕	◑	◑	◑	◕	◕	**63**
	Streetcar Tram	◑	◕	◑	◑	◕	◕	◑	◕	◑	◕	**63**
	Light Rail Vehicle	●	●	◑	◑	◕	◕	◑	●	◑	◕	**73**
	Diesel Multiple Unit – Articulated	◑	◕	◑	◑	◕	◑	◑	◑	◑	◕	**59**
Moderate Speed in Exclusive ROW	Conventional Bus - Standard 40’	●	◔	◕	◕	◕	◕	◕	●	◑	◑	**66**
	Conventional Bus - Articulated 60’	●	◔	◕	◕	◕	◕	◕	●	◑	◑	**68**
	Guided Bus	◑	◔	◕	◕	◑	◕	◕	◑	◔	●	**61**
	Streetcar Tram	◑	◕	◕	◑	◕	●	●	◕	◔	●	**69**
	Light Rail Vehicle	●	●	◕	◑	◕	●	●	●	◔	●	**79**
	Diesel Multiple Unit – Articulated	◑	●	◕	◑	◑	◑	●	◑	◔	●	**67**
	People Mover	●	●	◕	◑	◑	●	●	◕	◔	●	**78**
	Medium Monorail	◕	●	◕	◑	◑	●	●	◕	◔	●	**72**
	Large Monorail	●	●	◕	◔	◔	●	●	◑	◔	●	**70**
	Maglev	◑	●	◕	◑	◔	●	●	◔	◔	●	**65**
	Medium Rapid Rail	●	●	◕	◑	◑	●	●	●	◔	●	**80**
	Large Rapid Rail	●	●	◕	◑	◑	●	●	●	◔	●	**79**

Legend: ● = Excellent ◕ = Good ◑ = Moderate ◔ = Poor ○ = Fail

Table 4. Summary of the Technology Assessment by Transit Service Application (continued)

Type of Service / Technology		Technical Maturity	Line Capacity	Performance	Maneuverability	Cost / Affordability	Environmental	Safety	Supplier Competition	Implementation Time	Accessibility	Total Score (0-100)
High Speed in Exclusive ROW	Conventional Bus - Standard 40’	●	◔	◕	◕	◕	◕	◕	●	◑	◑	**67**
	Conventional Bus - Articulated 60’	●	◔	◕	◕	◕	◕	◕	●	◑	◑	**69**
	Guided Bus	◑	◔	◕	◕	◑	◕	◕	◑	◔	●	**61**
	Streetcar Tram	◑	◕	◕	◑	◕	●	●	◕	◔	●	**69**
	Light Rail Vehicle	●	●	●	◑	◕	●	●	●	◔	●	**81**
	Diesel Multiple Unit – Articulated	◑	●	●	◑	◑	◑	●	◑	◔	●	**69**
	People Mover	●	●	◕	◑	◑	●	●	◕	◔	●	**79**
	Medium Monorail	◕	●	◕	◑	◑	●	●	◕	◔	●	**73**
	Large Monorail	●	●	◕	◔	◔	●	●	◑	◔	●	**70**
	Maglev	◑	●	●	◑	◔	●	●	◔	◔	●	**67**
	Medium Rapid Rail	●	●	●	◑	◑	●	●	●	◔	●	**82**
	Large Rapid Rail	●	●	●	◑	◑	●	●	●	◔	●	**81**

Source: Lea+Elliott Inc., November 2005

Legend: ● = Excellent ◕ = Good ◑ = Moderate ◔ = Poor ○ = Fail

Technology Assessment Summary

The findings from the technology assessment above are summarized for each individual technology in the following section. Findings are given in terms of advantages, disadvantages and recommendations. Advantages and disadvantages are discussed in both absolute and relative terms. Recommendations focus on whether a technology should be included in the subsequent alternatives analysis where technology/alignment combinations form alternatives to be analyzed. Descriptions of the specific technologies are provided in Appendix A.

In more general terms, the findings from the technology assessment can be summarized as follows:

- No single technology emerged as far superior to others within any of the Types of Service.
- A number of technologies are found to be well suited for each of the Types of Service.
- For the two Mixed Traffic types of service, the Standard and Articulated Conventional Bus, and the Light Rail Vehicle scored highest and are recommended for inclusion in the alternatives analysis...
- For both the Exclusive ROW types of service, the Light Rail Vehicle, People Mover, Monorail, and Rapid Rail Vehicle technologies scored well and are recommended for inclusion in the alternatives analysis. The Maglev technology, which scored moderately, may also be considered for some forms of Exclusive ROW operations. Conventional Bus, which also scored moderately, will be considered for managed lane operations.

The Project Team has the option to use a single technology for an alternative, multiple technologies for an alternative, or a "composite" range of technologies that scored highly within the Type of Service that is applicable for a given alternative.

Depending on the project delivery (procurement) strategy that is chosen, it may be possible to let the marketplace decide the most appropriate technology through a "performance" rather than a "detailed design" specification process. This turnkey procurement process has been used for some urban transit systems, including Miami, Jacksonville, Detroit, San Juan, and a number of lines in New Jersey and would allow for greater competition among technology suppliers and result in lower capital costs.

The following sections describe the detailed findings for each of the technologies.

Conventional Bus Category – Standard Bus

The 40-foot long conventional standard bus primarily provides the Mixed Traffic and Limited Mixed Traffic (i.e., HOV lanes and other managed lanes) types of transit service. This technology can be used in Bus Rapid Transit (BRT) applications. It can also provide Exclusive ROW type of transit service in the form of busways, but this option is not being considered in this study due to the physical constraints of the corridor. The technology scored "Good" for Mixed Traffic and Limited Mixed Traffic types of service in absolute terms, and scored second highest in relative terms. The technology scores "Moderate" for both Exclusive ROW types of transit service.

<u>Advantages</u> – This technology has absolute advantages in technical maturity, maneuverability, costs (at-grade), supplier competition, and implementation time.

<u>Disadvantages</u> – This technology has disadvantages in line capacity and performance. In accessibility, in terms of ease of boarding, it scores "Moderate" due to lack of level boarding. It scores "Poor" in terms of safety primarily because of the potential for increased conflicts with other vehicles in mixed flow operations.

<u>Recommendation</u> – The conventional standard bus is a possible technology for alternatives with significant portions of mixed traffic operations although higher travel demand volumes (to be determined later in the Study) would favor the

articulated bus over the standard bus for line-haul service. The standard bus is recommended for analysis related to providing feeder service to a line-haul alignment. This technology will also be considered for service in limited mixed traffic conditions such as HOV lanes and other forms of managed lanes.

Conventional Bus Category – Articulated Bus

Similar to the standard bus, the articulated bus primarily provides the Mixed Traffic and Limited Mixed Traffic types of transit service. The technology is often the preferred size bus for a BRT application. Articulated buses can also provide Exclusive ROW type of transit service through the use of busways, but this option is not being considered in this study due to the physical constraints of the corridor. The technology scores "Good" for Mixed Traffic and Limited Mixed Traffic types of service in absolute terms and second highest in relative terms.

<u>Advantages</u> – This technology has absolute advantages in technical maturity, maneuverability, costs (at-grade), supplier competition, and implementation time.

<u>Disadvantages</u> – This technology scores somewhat lower than most other technologies in line capacity and performance. The technology scores "Moderate" for both Exclusive ROW types of transit service. Accessibility, in terms of ease of boarding, it scores "Moderate" due to lack of level boarding. It scores "Poor" in terms of safety primarily because of the potential for increased conflicts with other vehicles in mixed flow operations. <u>Recommendation</u> – Articulated conventional bus is a possible technology for alternatives with significant portions of mixed traffic operations. The articulated bus is recommended for analysis in providing high demand feeder service to a line-haul alignment. This technology is not recommended for analysis for line-haul alternatives with little to no at-grade operations. Recommended for a BRT application that does not need precision docking. This technology will also be considered for service in limited mixed traffic conditions such as HOV lanes and other forms of managed lanes.

Guided Bus Category - Guided Bus

Guided bus can be used in a BRT application and allows for precision docking and high-level boarding. This technology primarily provides Limited Mixed Traffic and Moderate-Speed Exclusive ROW types of transit service. It can also provide Mixed Traffic as well as High-Speed Exclusive ROW service through the use of guided busways, but this latter option is not being considered in this study due to the physical constraints of the corridor.. The technology scores between "Moderate" and "Good" for all types of transit service in absolute terms, and scores among the lowest in relative terms.

<u>Advantages</u> – This technology has an advantage in maneuverability (particularly if it is guided only at the station/stop).

<u>Disadvantages</u> – This technology has some disadvantages in technical maturity, line capacity, and supplier competition. It scores "Poor" in terms of safety primarily because of the potential for increased conflicts with other vehicles in mixed flow operations. .

Recommendation – A potential candidate for alternatives with significant portions of mixed traffic operations but due to its disadvantages, guided bus is not recommended for analysis for alternatives with exclusive right-of-way or for feeder service. Guided bus is recommended for any BRT alternatives if level boarding is a desired feature. It is assumed that these guided buses would also be articulated.

Light Rail Transit Category - Streetcar Tram

Streetcar trams are the smallest (length and width) vehicles in the Light Rail category. This technology primarily provides the Mixed Traffic and Limited Mixed Traffic types of transit service. It can also provide Exclusive ROW type of transit service though this is not typical. The technology scores between "Moderate" and "Good" in all types of service in absolute terms and scores among the lowest for both Mixed Traffic types of service and scored in the middle of the range for the Exclusive ROW type of service.

Advantages – This technology has advantages in costs (at-grade only), and environmental.

Disadvantages – This technology scored "Poor" in technical maturity, line capacity, supplier competition, and safety. It only scored "Moderate" in terms of performance in mixed traffic services. If the technology is to transition from mixed traffic to exclusive ROW along an alignment, there are technical issues (power collection, visual impact) that will be challenging.

Recommendation – Streetcar Tram is not recommended for any line-haul alternatives. This technology is might be considered for feeder service.

Light Rail Transit Category - Light Rail Vehicle

This technology is the "standard" Light Rail vehicle (90-foot in length) and primarily provides the Mixed Traffic and Limited Mixed Traffic types of transit service. It can also provide Exclusive ROW type of transit service though this is not typical. The technology scores "Good" for the Mixed Traffic types of service and between "Good" and "Excellent" for the Exclusive ROW types of service in absolute terms. It scores among the best for each type of service in relative terms.

Advantages – This technology had advantages in performance, costs (at-grade only), environmental, supplier competition and accessibility.

Disadvantages – This technology scored only "Moderate" in line capacity, performance, and implementation time in mixed traffic services. If the technology is to transition from mixed traffic to exclusive ROW along an alignment, there are technical issues (power collection, visual impact) that will be challenging. It scored "Poor" in terms of safety.

Recommendation – Light Rail is a strong technology for alternatives with limited portions of mixed traffic and predominately exclusive ROW although the transition between the two types of service will pose technical challenges. This technology is also recommended for analysis for line-haul alternatives with exclusive ROW.

Light Rail Transit Category - Diesel Multiple Unit (Articulated, Single Level)

This technology includes vehicles that are not FRA-compliant and is very similar to the standard Light Rail vehicle except that its power source is an on-board diesel electric power plant. This type of DMU primarily provides the Limited Mixed Traffic types of transit service. It can also provide Exclusive ROW type of transit service. The technology scores "Moderate" in Mixed Traffic service and "Good" for Exclusive ROW service in absolute terms. In relative terms, it scored the lowest in Limited Mixed traffic and it scored in the middle of the range for Exclusive ROW types of service.

Advantages – This technology has absolute, but not relative, advantages in accessibility.

Disadvantages – This technology scores "Moderate" in technical maturity, maneuverability, cost/affordability, environmental and supplier competition.

Recommendation – DMU scores relatively poorly in the Limited Mixed traffic type of service and only moderately (relative) in the Exclusive ROW types of service, and is not recommended for inclusion in the alternatives analysis.

People Mover Category – Automated People Mover (APM)

This technology provides only Moderate- and High-Speed, Exclusive ROW type of transit service. The technology scores between "Good" for both Exclusive ROW types of transit service in absolute terms and scores among the best in relative terms.

Advantages – The APM technology has advantages in technical maturity, line capacity, environmental, safety and accessibility.

Disadvantages – This technology scores only "Moderate" in cost and maneuverability. It also scores "Poor", though relatively well, in terms of implementation time for Exclusive ROW technology applications. A slight disadvantage is found in performance as the top speed is often below that of the higher capacity rail technologies.

Recommendation – APM is a possible technology for alternatives with only Exclusive ROW and the higher speed versions (45 mph or higher cruise speed) of the technology are recommended for inclusion in the line-haul alternatives analysis. This technology is recommended as a technology for feeder service serving high demand areas that may not be served by the line-haul alignment, such as Waikiki and the Airport.

Monorail Category – Medium Monorail

This technology provides only Moderate- and High-Speed, Exclusive ROW type of transit service. The technology scores "Good" for both Moderate- and High-Speed Exclusive ROW types of transit service in absolute terms and scores in the middle of the range in relative terms.

Advantages – Medium Monorail technology has advantages in line capacity, environmental, safety and accessibility.

Disadvantages – This technology scores "Moderate" in cost and maneuverability. It also scores "Poor", though relatively well, in terms of the implementation time for Exclusive ROW technology applications.

Recommendation – Medium Monorail scores "Good" for line-haul alternatives with Exclusive ROW and is recommended for inclusion in the alternatives analysis although it is not among the highest scoring of the technologies. Medium Monorail is a potential candidate for feeder service (i.e., Waikiki, Airport).

Monorail Category – Large Monorail

This technology provides only Moderate- and High-Speed, Exclusive ROW type of transit service. The technology scores "Good" for both types of service in absolute terms and scores in the middle of the range in relative terms.

Advantages – This technology has advantages in technical maturity, line capacity, environmental, safety and accessibility.

Disadvantages – This technology scores "Poor" in maneuverability and cost. It also scores "Poor", though relatively well, in terms of implementation time for Exclusive ROW technology applications. It scores "Moderate" in terms of supplier competition. Large Monorails have a slight disadvantage in performance (top speed) compared to the higher capacity rail technologies.

Recommendation – Large Monorail scores "Good" for line-haul alternatives with Exclusive ROW and is recommended for inclusion in the alternatives analysis although it was not among the highest scoring.

Maglev Category - Maglev

Within the Maglev category, this specific technology is considered "low speed" for a Maglev technology: the 60-mph cruise speed is as fast as any other technology under consideration for Honolulu. This technology only provides Moderate- and High-Speed, Exclusive ROW type of transit service.

Advantages – The Maglev technology has advantages in line capacity, environmental, safety and accessibility.

Disadvantages – This technology scores "Poor" in cost and supplier competition. It also scores low, though relatively well, in terms of implementation time for Exclusive ROW technology applications. It scores "Moderate" in terms of technical maturity and maneuverability.

Recommendation – Maglev scores in the low end of the "good" range within both Moderate- and High-Speed Exclusive ROW service types. It was the lowest scoring of the fixed guideway technologies but is still recommended for inclusion in the alternatives analysis. It is not recommended for feeder service.

Rapid Rail Transit Category - Medium Rapid Rail Vehicle

This technology provides only Moderate- and High-Speed, Exclusive ROW type of transit service. This technology can be either automated or manually driven. The findings presented below assume a non-automated system. Findings for automated medium rapid transit are similar to that of People Mover but with slightly better performance (cruise speed). The technology scores between "Good" and "Excellent" for both Moderate- and High-Speed Exclusive ROW types of transit service in absolute terms and is the highest scoring technology in relative terms.

Advantages – This technology has advantages in technical maturity, line capacity, performance, environmental, safety, supplier competition and accessibility.

Disadvantages – This technology scores "Moderate" in maneuverability and cost. It also scores "Poor", though relatively well, in terms of implementation time for Exclusive ROW technology applications.

Recommendation – Medium Rapid Transit is a strong technology for line-haul alternatives with only Exclusive ROW and should be included in the alternatives analysis.

Rapid Rail Transit Category - Large Rapid Rail Vehicle

This technology only provides Moderate- and High-Speed, Exclusive ROW type of transit service. This technology can be either automated or manually driven.

Advantages – This technology has advantages in technical maturity, line capacity, performance, environmental, safety, supplier competition and accessibility. The technology scores between "Good" and "Excellent" for both Moderate- and High-Speed Exclusive ROW types of transit service in absolute terms and scores among the highest in relative terms.

Disadvantages – This technology scores only "Moderate" in maneuverability and cost. It also scores "Poor", though relatively well, in terms of implementation time for Exclusive ROW technology applications. It is slightly less maneuverable than Medium Rapid Transit, which could limit its effectiveness in the downtown area.

Recommendation – Large Rapid Transit is a strong technology for alternatives with only Exclusive ROW and should be included in the alternatives analysis. Medium Rapid Transit is quite similar in many respects and scores slightly higher and therefore the Project Team may want to analyze Medium Rapid Transit but not Large Rapid Transit as a means of consolidating its analysis. This would not preclude Large Rapid Transit from further consideration as suppliers could certainly propose in a performance-based competition.

Chapter 4 Corridor Transit Service Integration

This chapter discusses the conceptual requirements for interfacing and integrating the different levels of transit services within the corridor to function as an overall, coordinated system. The Corridor will benefit from an integrated transit system to serve the multiple trip components described in the following section.

Trip Components

Considering a typical trip that could use the new transit service envisioned in the HHCTC Project, there are three basic trip components: origin collection, line haul, and destination distribution. These components are described as:

- The origin collection component is how a traveler accesses transit for the trip. It includes options such as directly accessing a line haul station (walking, biking, driving or being dropped off) or riding a feeder transit system to the line haul station. It could also be served by a bus or fixed guideway service that, after collecting passengers within a defined local service area, transitions to a line haul function.
- The line haul component typically encompasses the majority of the overall distance traveled between trip origin and destination. The higher overall average travel speed provided for this portion of the trip, the higher the functionality provided. This component is the primary focus of the HHCTC Project.
- The destination distribution component is how a traveler makes the last leg of their trip. The options are the same as for the origin collection component.

One-, Two-, or Three-Seat Rides

The origin-collection and destination-distribution components could use the same or different transit modes from the line-haul component. When all trip components use the same mode this is termed a "one-seat ride". The transit rider boards the transit vehicle relatively close to his or her destination and is transported to a location near his or her destination without transfers. A "three seat ride" is if the rider must use one form of transit to travel from origin to the line-haul mode, transfer to a second mode for the line-haul portion, and transfer to a third mode to reach the final destination. A "two-seat ride" requires only one transfer during the trip. Generally, transfers are viewed negatively because of increased time uncertainty and wait time that is perceived as much longer than time spent traveling on the transit mode.

While a one-seat ride, like most auto trips, is best for a rider, it is impossible to serve all origins and destinations with a time-effective transit service. In locations of low to moderate population and employment densities, the collection and distribution components of a trip can require relatively slow average travel speeds due to circuitous routes and frequent stops. Typically only areas of high density can be well served with the same mode as the line-haul mode. Therefore, it is likely that only the densest portion of the urban core areas in the corridor will be provided with transit stops located within walking distance to most destinations. Other transit trips will need a well-located and -scheduled multiple-mode feeder-line haul system.

Line Haul Versus Feeder/Local

To serve the low- to moderate-density areas, transit services that “feed” the line haul transit line will be needed. Transit routes that just serve the local area could be combined with this feeder service or operated separately. These feeder/local modes will not necessarily use the same transit technologies as the line-haul service.

Table 5 shows that no one transit technology category is the best at both line haul and feeder/local service. The HHCTC Project potentially includes all four types of service: Mixed Traffic, Limited Mixed Traffic, Moderate-Speed in Exclusive Right of Way, and High-Speed in Exclusive Right of Way. Each of these four types of service might apply to given segments along the "line-haul" portion of the Corridor and the first three types of service might apply to portions of the Corridor that "feed" into the line-haul system. Table 5 shows the ability of the screened technologies to perform as both line-haul and feeder systems. This distinction compares similarly to the Types of Service screening presented in Table 2.

Table 5. Potential Technology Applications

Technology	Line-Haul	Local/Feeder
Conventional Bus	○[1]	●
Guided Bus	●	○
Light Rail Transit – Streetcar Tram	○	●
Light Rail Transit – Light Rail Vehicle	●	○
Light Rail Transit – Diesel Multiple Unit, Articulated	●	○
People Mover	○	●
Monorail – Medium	○	●
Monorail – Large	○	●
Maglev	●	×
Rapid Rail Vehicle – Medium	●	×
Rapid Rail Vehicle – Large	●	×

Source: Lea+Elliott, Inc., November 2005

Legend: ● = Primary Application; ○ = Secondary Application; × = Not Applicable

[1] Conventional bus may be considered as a primary application for line haul service operating on managed lanes

A key to having a well-integrated transit system with transfers is the integration of routes at the transfer points. Physically, the transfer facilities should be designed to minimize the walking distance between modes and provide logical connections. Stations should be easily accessible from the key auto and bus routes on the local roadway network. Sufficient space should be provided for adequate station facilities including mode transfer and parking. To the extent possible, stations should be located at local activity centers to maximize walk access to the station.

Transit service schedules should be integrated to minimize wait times for the majority of riders. Systems that provide for short headways inherently minimize wait times. Feeder/local modes often have longer headways than the line haul mode so coordinated scheduling is important.

From a technology standpoint, maintenance of transit equipment in the corridor should also be considered. While multiple technologies are likely to be required, the owner(s)/operators of the systems will want to provide some level of standardization. The extent that this is desirable should be a factor in planning the overall transit system in the corridor.

Appendix A Transit Technology Descriptions

Transit Technology Descriptions

This Appendix presents descriptions of the transit technologies that remained after the initial screening described in Chapter 3. These generalized descriptions provide highlights that relate to important considerations in the HHCTC Project. The descriptions are based on sample technologies to provide representative dimensions, weights, and performance characteristics.

The data are presented for vehicles that are comprised of one or more cars. A car that is not a complete vehicle is an individual passenger unit that that cannot operate individually, but must be connected with other cars to form a vehicle. A combination of vehicles coupled together is a consist or train. For many of the technologies discussed herein, different numbers of cars can be combined together to form a vehicle depending upon the application. Where applicable, the text descriptions identify the number of cars per vehicle assumed for data presentation purposes.

Table A-1 presents comparative data for the technologies on passenger capacity and vehicle weights. These data are referred to in the technology descriptions to provide comparison among technologies.

The passenger carrying capacity per unit of length is shown to indicate the passenger efficiency of a technology. For a given passenger load, more efficient technologies would require a shorter berthing area at stops or stations.

Comparisons of vehicle weights normalized by the vehicle length and number of weight bearing areas supporting the vehicle weight are also shown in the tables. The weight per length shows that transit vehicles fall generally within a relatively small range. The weight stress loading columns of the table provides a relative comparison of the weights for which an elevated structure would be designed. For this measure, the total vehicle weight is divided by the number of "weight bearing areas" on the vehicle.

A weight bearing area is the general concentrated area that the vehicle load is transferred to the supporting structure. For buses, the weight bearing area is an axle since transit buses have single axles located near each end of the vehicle. For steel rail-based vehicles, the weight bearing area is a truck since the vehicle weight is transferred among the two axles in a truck over a relatively small area of six or seven feet. For monorails and people movers, the weight bearing area is a bogie, which may be one or two axles each, depending upon the technology.

The passenger carrying efficiency and weight stress loading are ranked low, moderate, or high to provide some general groupings of these characteristics for the various technologies under consideration.

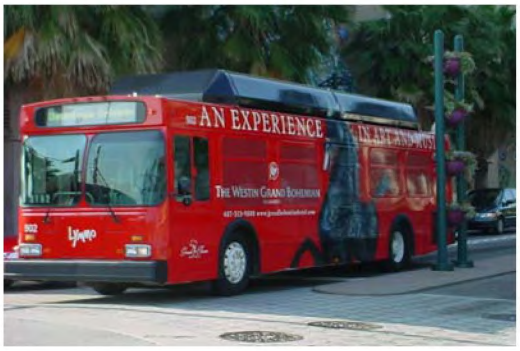
Table A-1. Transit Technology Comparative Passenger Capacity and Weight Characteristics

Technology	Passenger Capacity Efficiency		Empty Vehicle Weight per Foot of Length (pounds)	Weight Stress Loading	
	Passengers per Foot of Length	Rank		Empty Vehicle Weight per Bearing Area (pounds)	Rank
Conventional Bus – Standard	1.5	Low	700 – 800	14,000 – 16,000 per axle	Low
Conventional Bus – Articulated	1.5	Low	650 – 750	13,000 – 15,000 per axle	Low
Guided Bus	1.6	Low	550 – 800	11,000 – 16,000 per axle	Low
Light Rail Transit – Streetcar Tram	1.5-1.6	Low	800 – 1,150	24,000 – 26,500 per truck	Mod.
Light Rail Transit – Light Rail Vehicle	2.1	Mod	1,050 – 1,200	32,000 – 36,000 per truck	High
Light Rail Transit – Diesel Multiple Unit, Articulated	2.0	Mod	1,150	38,500 per truck	High
People Mover – Automated People Mover	2.0-2.2	Mod	750 – 1,000	15,000 – 21,000 per bogie	Low
Monorail - Medium-sized Monorail	1.6-2.3	Low-High	600 – 1,100	11,000 to 26,500 per bogie	Low-Mod.
Monorail – Large –sized Monorail	2.2-2.3	High	1,450	34,000 – 37,500 per bogie	High
Maglev	2.1	Mod.	850	7,900 per levitation module	Low
Rapid Rail Vehicle – Medium-sized (Type 1)	2.2-2.7	High	850 - 900	24,500 – 26,500 per truck	Mod.
Rapid Rail Vehicle – Medium-sized (Type 2)	2.3	High	1,400	35,000 per truck	High
Rapid Rail Vehicle – Large-sized	2.3	High	1,100	38,500 to 41,500 per truck	High

Bus

Buses are the workhorses of the transit industry with many thousands of units deployed worldwide. Standard urban buses used for transit service are typically 40 feet in length and have the characteristics shown in the table below. Smaller buses, between 22 to 36 feet, are also available. They can have either high or low floors. A low floor is typically about 14 inches above the ground surface. They may be powered with internal combustion engines using diesel or alternative fuels such as compressed natural gas (CNG) or hybrid configurations such as diesel-electric engines. Buses powered exclusively by batteries are currently not realistic candidates for the line-haul function in the HHCTC Project primarily due to limitations of battery charge life, vehicle sizes, and bus speeds.

Trolley buses using electric motors are also included here as the only difference is the source of power. The overhead wire distribution system (OWDS) required, however, would typically limit bus speeds, as noted in the table, and operating/route flexibility. Buses are among the least efficient technologies in terms of passengers carried per foot of length, but are the most flexible since they can travel on roadways in mixed traffic. Their vehicle weights per bearing area (axle in this case) are among the lowest for the transit technologies under consideration in this study.

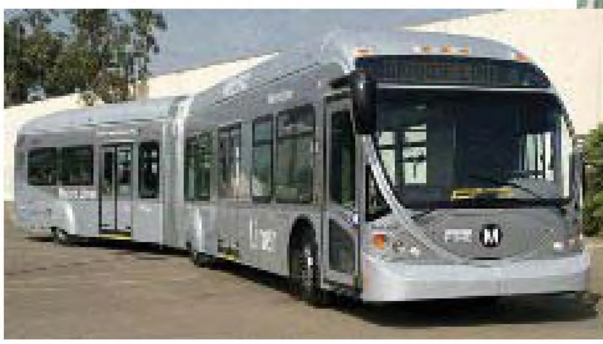


Conventional 40-foot Standard Bus on the Lymmo system in Orlando, Florida, at left, and in Honolulu, at right.

Element	Typical Characteristics
Vehicle Dimensions	*Length*: 40 to 45 ft *Width*: 8.5 ft *Height:* 10 to 11 ft
Vehicle Capacity/ Max. Cruise Speed	*Capacity*: 60 passengers (at 2.7 sq ft per standing pass.) *Cruise Speed*: 55 mph
Consist Sizes	Single vehicles only.
Min. Horizontal Turning Radius	39 to 44 ft
Empty vehicle Weight	28,000 to 32,000 pounds on two axles.
Power Source	On-board powerplant or overhead wire distribution system (OWDS) which typically limits cruise speed to 40 to 43 mph.
Suspension	Rubber tires.
Sample Suppliers/ Applications	Suppliers: Gillig, Neoplan, New Flyer, NABI, Nova, Orion, Van Hool, Volvo; Sample Applications: Honolulu, San Francisco, Los Angeles, Seattle, and numerous others.

Conventional Bus - Articulated (Single- and Bi-articulated)

Articulated buses are also deployed in transit applications worldwide, most commonly as 60-foot single-articulated vehicles. This type of bus is a typical choice for Bus Rapid Transit (BRT) applications. Bi-articulated buses, 80 feet in length, can be used for special BRT applications, but are in limited use today in the U.S. These vehicles can be fully high floor, fully low floor, or be mostly low floor with some high floor areas over one or more axles. They generally have the same power plant and power source options as conventional standard buses. While they are similar to 40-foot buses in terms of passengers-per-foot capacity, they are more efficient since a single bus driver can transport more people. Articulated buses have similar weights-per-bearing area to standard buses.

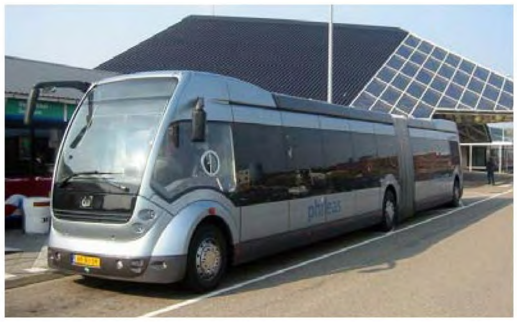


An articulated trolley bus in Seattle, Washington, above, and a NABI low floor, single-articulated bus, at left

Element	Typical Characteristics
Vehicle Dimensions	*Length*: 60 to 80 ft *Width*: 8.5 ft *Height:* 10 to 11 ft
Vehicle Capacity/ Max. Cruise Speed	*Capacity*: 90 to 120 passengers (at 2.7 sq ft per standing pass.) *Cruise Speed*: 55 to 62 mph
Consist Sizes	Single vehicles only.
Min. Horizontal Turning Radius	39 to 44 ft
Empty vehicle Weight	39,000 to 58,000 pounds on three axles for single-articulated buses and four axles for bi-articulated buses.
Power Source	On-board powerplant or OWDS, which typically limits cruise speed to 40 to 43 mph.
Suspension	Rubber tires.
Sample Suppliers/ Applications	Suppliers: New Flyer, NABI, Van Hool, Neoplan, Volvo; Sample Applications: Honolulu, Seattle and numerous applications worldwide.

Guided Bus (Single- and Bi-articulated)

Guided buses may be specialized applications of conventional single and bi-articulated buses or be a rubber-tired version of a streetcar tram. Typically, modern versions of these vehicles feature low floors and extra-wide doors. Guidance can be provided by mechanical side guidewheels/rails, an embedded rail or slot in the road, optical scanners, or magnetic sensors embedded in the road. Guidance can be used to provide precision docking at stops to permit level vehicle boarding. Guidance can also be used along the route in exclusive right of ways to reduce the space required for a busway, but the guidance mechanism will typically restrict bus speeds to below 43 miles per hour due to safety and ride quality requirements. Drivers are required for bus operations in exclusive lanes or on separate busways since they control acceleration and speed even if steering is provided by the guidance system. Most buses can be steered normally when they are off guidance, but some have only "shop" steering, which is off-guidance manual steering that is only intended for low-speed, maintenance yard movements. For those with normal non-guided steering, normal bus speeds are also possible when the bus is not in the guided mode. Power choices are similar to conventional buses. Safe power collection systems embedded in the pavement are still in the research and development stage. There are multiple suppliers, but each bus design is proprietary due to the guidance mechanism.

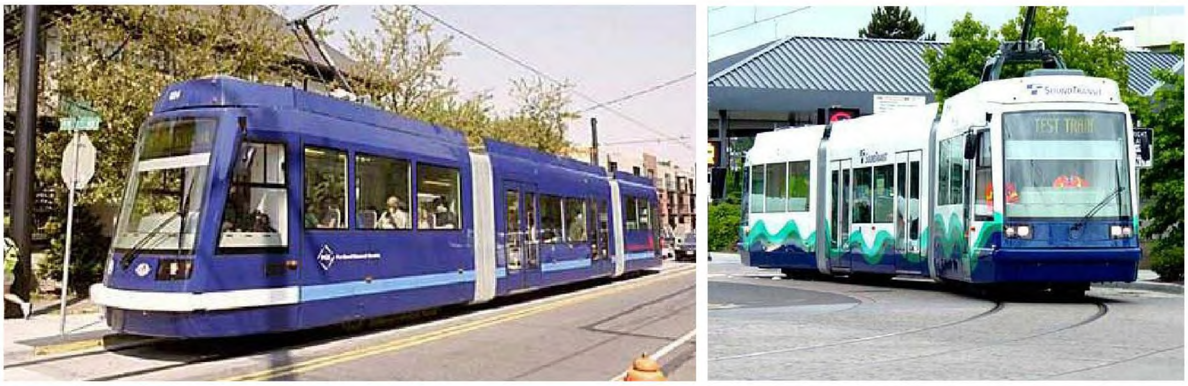


The Bombardier GLT, on left, uses OWDS and slot guidance. The Phileas bus, on right, uses embedded magnets for guidance and has all-wheel steering for docking

Element	Typical Characteristics
Vehicle Dimensions	*Length*: 60 to 80 ft *Width*: 7.2 to 8.5 ft *Height:* 10 to 11 ft
Vehicle Capacity/ Max. Cruise Speed	*Capacity*: 60 to 128 passengers (at 2.7 sq ft per standing pass.) *Guided Cruise Speed*: 43 mph
Consist Sizes	Single vehicles only.
Min. Horizontal Turning Radius	39 to 44 ft
Gross Vehicle Weight	34,000 to 58,000 pounds on three axles for single-articulated buses and four axles for bi-articulated buses.
Power Source	On-board powerplant or OWDS
Suspension	Rubber tires.
Sample Suppliers/ Applications	Irisbus CIVIS in Las Vegas, Nevada (MAX) and Roene, France; Bombardier GLT in Caen and Nancy, France; TransLohr in Clermont-Ferrand, France and Padova, Italy; Phileas in Eindhoven, Netherlands.

Light Rail Transit – Streetcar Tram

Modern Streetcar Trams, similar to those shown in the pictures, are discussed here rather than historic streetcars. These vehicles are shorter, narrower, and lighter than standard Light Rail Vehicles (LRVs). Typically, these vehicles feature two articulations and modern versions usually have mostly low floors. Full low floor vehicles can be more expensive to buy and maintain than partial (70 percent) low floor vehicles that have step-ups to high floors over two of the wheel/axle areas. This cost difference is primarily due to space constraints that require the use of stub axles, hub motors, and other space saving components. Streetcar Trams are primarily intended to operate in mixed traffic on streets. They run on steel rails embedded in the street and obtain power from an OWDS. For operations in mixed traffic, they require an on-board driver. Specific vehicle designs can be owned by a transit authority or be proprietary to a supplier, but all light rail transit vehicles can operate on essentially any light rail system if they have the correct power collection and train control subsystems. Since Streetcar Trams are narrower that standard LRVs, they have passenger carrying capacities per foot of length more similar to guided buses. Their weights per bearing area are higher than buses but lower than standard LRVs.

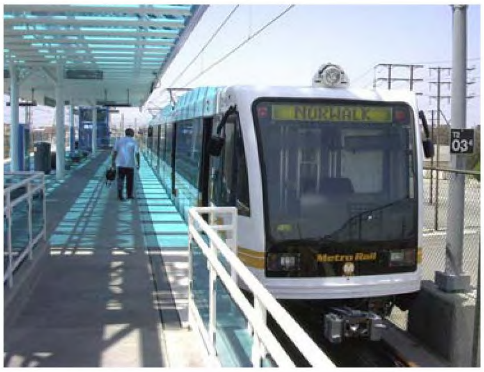


Skoda Astra Streetcar Trams in Portland, Oregon, at left, and in Tacoma, Washington, at right.

Element	Typical Characteristics
Vehicle Dimensions	*Length*: 66 to 75 ft *Width*: 7.5 to 8.0 ft *Height:* 11.2 to 11.8 ft
Vehicle Capacity/ Max. Cruise Speed	*Capacity*: 100 to 120 passengers (at 2.7 sq ft per standing pass.) *Cruise Speed*: 43 to 46 mph
Consist Sizes	One to three vehicles per train. Shorter trains may be necessary for mixed traffic applications due to street block lengths.
Min. Horizontal Turning Radius	40 to 50 ft
Empty Vehicle Weight	53,000 to 72,500 pounds on two or three trucks (two axles per truck)
Power Source	OWDS
Suspension	Steel wheels on steel rails.
Sample Suppliers/ Applications	Skoda-Inekon Astra: Portland and Tacoma Streetcar; Bombardier and Alstom, various applications in Europe.

Light Rail Transit – Light Rail Vehicle

Light Rail Vehicles (LRVs) operate in a variety of types of applications throughout North America and elsewhere in the world. They have one or two articulations per vehicle and can have high floors or floors that are about 70 percent low-floor with step-ups to high floors over two of the wheel/axle areas. With raised station platforms, level boarding can be provided for high or low level floors. Level boarding with high floors, however, would restrict the number of doors available for low level boarding in a mixed traffic application. LRVs can be controlled automatically in an exclusive right of way (such as, San Francisco Muni in tunnel), but almost all have a driver operating the vehicles, whether in mixed traffic or exclusive right of way. The source of power is usually an OWDS, but third rail power has been used in exclusive right of ways. Specific vehicle designs can be owned by a transit authority or be proprietary to a supplier, but all LRVs can operate on essentially any light rail system if they have the correct power collection and train control subsystems. Due to its larger size, a standard LRV is moderately efficient in terms of passenger carrying capacity, but it does have a relatively high weight per bearing area.

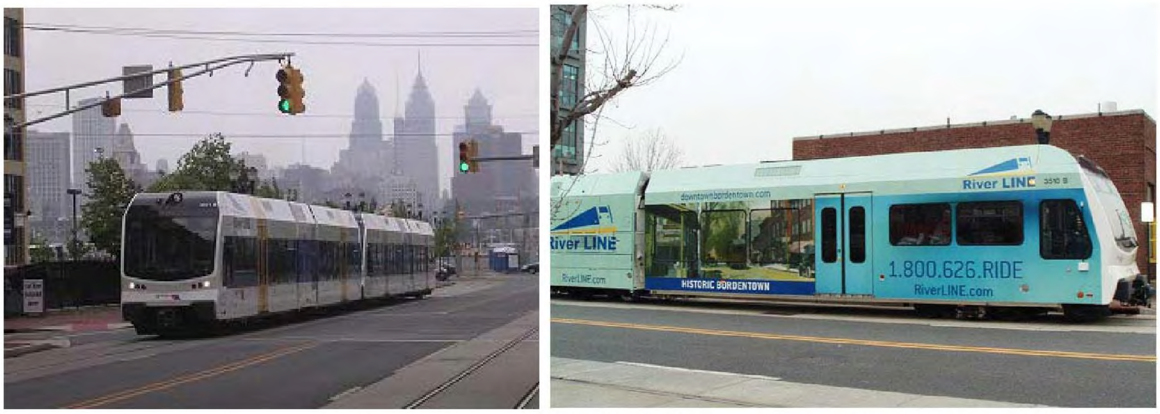


Light Rail Vehicles on the Green Line in Los Angeles, California, at left and on the MAX system in Portland, Oregon.

Element	Typical Characteristics
Vehicle Dimensions	*Length*: 90 ft 28 m *Width*: 8.8 ft *Height:* 10.8 to 12.5 ft
Vehicle Capacity/ Max. Cruise Speed	*Capacity*: 185 passengers (at 2.7 sq ft per standing pass.) *Cruise Speed*: 55 to 65 mph
Consist Sizes	One to four vehicles per train. Shorter trains may be necessary for mixed traffic applications due to street block lengths.
Min. Turning Radius	85 ft
Empty Vehicle Weight	96,000 to 109,000 pounds on three trucks (two axles per truck).
Power Source	OWDS, usually, but third rail is possible.
Suspension	Steel wheels on steel rails.
Sample Suppliers/ Applications	Suppliers: Alstom, Ansaldobreda, Bombardier, Kawasaki, Kinki Sharyo, Nippon Sharyo, Siemens. Sample U.S. Applications: Boston, Los Angeles, Pittsburgh, Portland, St Louis, and San Diego.

Light Rail Transit– Diesel Multiple Unit (DMU) – Articulated - Single Level

This Diesel Multiple Unit (DMU) is configured as a light rail vehicle with an on-board diesel-electric powerplant. The vehicle has two articulations and, as deployed on the Trenton-Camden River Line, has about two-thirds semi-low floor that is 23 inches above the top of rail. The River Line has station platforms raised to this floor elevation. Passengers use the two, long end sections of the vehicle while the center section is for propulsion and auxiliary power equipment. The vehicle has two doors per side compared with four doors for a LRV. The passenger carrying efficiency is slightly less than a standard LRV and its weight per bearing area is among the highest of the technologies considered.

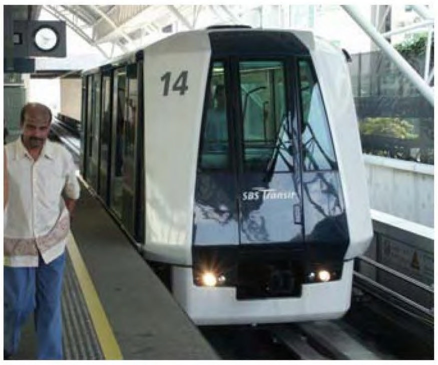


Stadler-Bombardier's GTW 2/6 DMU for a light rail application, on the Trenton-Camden, New Jersey River Line.

Element	Typical Characteristics
Vehicle Dimensions	*Length*: 102 ft *Width*: 9.8 ft *Height:* 12.8 ft
Vehicle Capacity/ Max. Cruise Speed	*Capacity*: 200 passengers (at 2.7 sq ft per standing pass.) *Cruise Speed*: 60 mph
Consist Sizes	One to two vehicles per train.
Min. Horizontal Turning Radius	132 ft
Empty Vehicle Weight	115,000 pounds on three trucks (two axles per truck).
Power Source	On-board power plant (diesel-electric)
Suspension	Steel wheels on steel rails.
Sample Suppliers/ Applications	Stadler-Bombardier (formerly an Adtranz product) GTW, New Jersey RiverLine

People Mover – Automated People Mover (APM)

The people mover vehicle technologies described here are at the upper end of the range, in terms of vehicle size and speed, for people movers. Other smaller technology sizes are available; however, those are less applicable to the line haul function for HHCTC Project primarily due to their lower passenger capacity. A primary application has been at major activity centers, such as airports and downtowns, but numerous urban transit APM systems exist in France, Italy, and Japan. These vehicles are typically supported on rubber tires and operate under automatic, driverless control. A driverless mode permits more cost effective operations on short headways to minimize waiting time for passengers. Some systems, particularly in Japan, have drivers that act more as attendants than operators as the vehicles remain largely under automatic control. People Movers feature level boarding and operate under strict ride comfort parameters, permitting most passengers to stand thereby increasing passenger carrying efficiency to moderately high levels. The vehicles typically have two, wide doors per side. The table describes characteristics for single car vehicles, but many applications use married-pairs. System designs are proprietary and are not interchangeable with other People Mover technologies. The vehicles have weights per bearing area that are near the low end of the range for technologies under consideration.

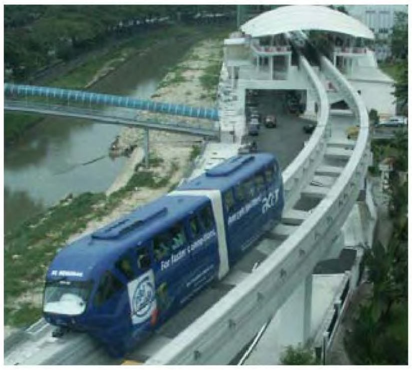


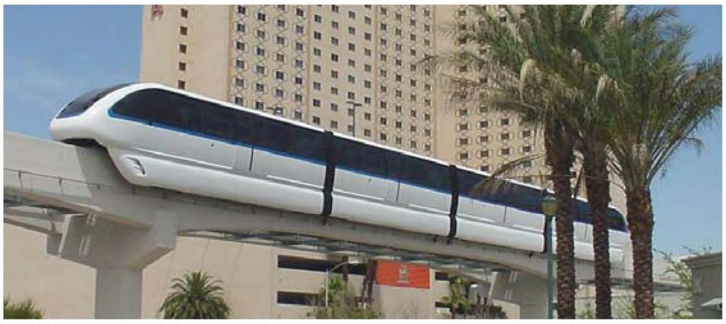
Mitsubishi's Crystal Mover on the Sengkang/Punggol lines in Singapore (left), and Siemens-Matra Val 208 in Lille, France.

Element	Typical Characteristics
Vehicle Dimensions	*Length*: 37 to 43 ft *Width*: 6.8 to 9.5 ft *Height:* 11 to 12 ft
Vehicle Capacity/ Max. Cruise Speed	*Capacity*: 90 to 100 passengers (at 2.7 sq ft per standing pass.) *Cruise Speed*: 32 to 50 mph
Consist Sizes	One to four vehicles per train.
Min. Horizontal Turning Radius	72 to 131 ft
Empty Vehicle Weight	30,000 to 42,000 pounds on two bogies.
Power Source	Third rail
Suspension	Rubber tires
Sample Suppliers/ Applications	Bombardier CX-100 and Innovia: Miami Metromover, Singapore-Bukit Panjang LRT, numerous airports; Mitsubishi Crystal Mover: Singapore -Sengkang/Punggol lines, several airports; Siemens Matra, Val 208/258: Lille (2 lines), Toulouse (2 lines), Rennes, France, Turin, Italy; Other Japanese systems: Kobe (2 lines), Osaka, Yokohama, Tokyo.

Monorail – Medium-sized

Most operating medium-sized monorails are straddle beam-type vehicles, which are described here. A vehicle is comprised of multiple cars creating an articulated unit. System designs are proprietary and are not interchangeable with other technologies. Monorails operate on an exclusive guideway and can be automated. Straddle beam monorail vehicles are supported and guided by a series of rubber tires. Large load tires that travel on top of the beam carry the train weight. Guide tires grip the sides of the beam to secure the vehicle to the guideway and steer the train. Vehicles that place the load tires beneath the floor, such as the Hitachi and Monorail Malaysia vehicles, are taller but permit passengers to walk between cars. The Bombardier monorail is lower in height but does not have the walkthrough capability. This characteristic does give the Bombardier monorail a relatively low unit weight. Medium-sized monorails are distinguished from large size versions by car sizes. While a variety of car-vehicle combinations are possible, the vehicles represented in the table here have four cars per vehicle. The Bombardier and Hitachi vehicles are similar in width and capacity at the lower end of the range shown. The Monorail Malaysia vehicle, based on the original Seattle Monorail's Alweg design, is wider and approaches the large monorail's high passenger capacity per unit of length. The Bombardier and Hitachi vehicles represented here have relatively low passenger efficiencies.



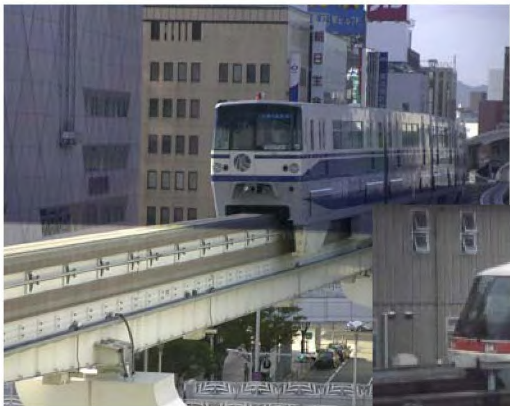


Monorail Malaysia in Kuala Lumpur, at left, and Bombardier's M-VI Monorail in Las Vegas, above.

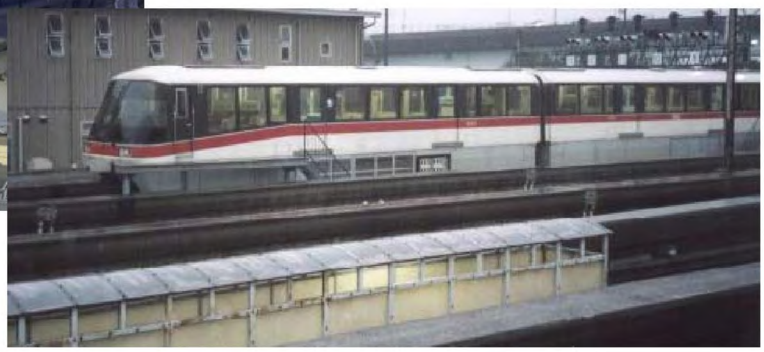
Element	Typical Characteristics
Vehicle Dimensions	*Length*: 121 to 138 ft *Width*: 8.2 to 9.8 ft *Height:* 11 to 15.3 ft
Vehicle Capacity/ Max. Cruise Speed	*Capacity*: 220-300 passengers (at 2.7 sq ft per standing pass.) *Cruise Speed*: 37 to 50 mph
Consist Sizes	One to two vehicles per train.
Min. Horizontal Turning Radius	131 to 230 ft
Empty Vehicle Weight	82,500 to 141,000 poundson eight bogies (Bombardier/Monorail Malasia) to 132,000 pounds on five bogies (Hitachi).
Power Source	Third rail
Suspension	Rubber tires
Sample Suppliers/ Applications	Bombardier, Las Vegas; Hitachi, Sentosa, Singapore, Monorail Malaysia, Kuala Lumpur

Monorail – Large-sized

Most operating large-sized monorails are straddle beam-type vehicles. They are similar to the medium sized monorails except they have larger cars and walk-through capability. While a variety of car-vehicle configurations are possible, the table represents three cars per vehicle. These systems are typically elevated and have level boarding at stations. System designs are proprietary and are typically not interchangeable with other monorail technologies. Since they operate on an exclusive guideway, they can be automated although most of the applications in Japan feature a driver on board with Automatic Train Protection (ATP) and sometimes Automatic Train Operation (ATO). Large-sized monorails are relatively high in terms of passenger carrying efficiency. They are also relatively heavy vehicles with weights per bearing area approaching large rapid transit vehicles.



Hitachi's Kita-Kyushu Monorail, at left, and the Tokyo Monorail, below.



Element	Typical Characteristics
Vehicle Dimensions	*Length*: 140 to 155 ft *Width*: 9.5 to 9.8 ft *Height:* 16.7 to 17 ft
Vehicle Capacity/ Max. Cruise Speed	*Capacity*: 315 to 345 passengers (at 2.7 sq ft per standing pass.) *Cruise Speed*: 37 to 50 mph ()
Consist Sizes	One to two vehicles per train.
Min. Horizontal Turning Radius	230 ft
Empty Vehicle Weight	205,000 to 224,500 pounds on six bogies.
Power Source	Third rail
Suspension	Rubber tires
Sample Suppliers/ Applications	Hitachi: Japan – Kita-Kyushu, Naha, Osaka, Tama, Tokyo-Haneda.

Maglev (Low Speed)

This is a relatively new technology that has one operating system in Nagoya, Japan: the Linimo. The system design is proprietary and is unlikely to be interchangeable with other maglev technologies. These vehicles travel along rails beneath the vehicle and are suspended using attractive magnetic levitation. They are propelled with linear induction motors (LIM) so, while it is moving, the only physical interaction, beyond magnetic forces, between the vehicle and the guideway is the contact with the third rail for power. The system features level boarding at stations and the trains have a "walk through" design. The Linimo has an attendant in the driver's position, but operates under full ATO. The Linimo vehicle, model 100 L is represented in the table below and is comprised of three cars per vehicle. The supplier, CHSST, also has a shorter vehicle, model 100 S, that operates on a test track. Switching is accomplished similar to a monorail with "beam replacement". That is, the entire running surface module moves to a new position. These vehicles are moderately efficient in terms of passenger carrying capacity per unit of length. They also fall in the low range in terms of weight per bearing area because the levitation modules are spread across the length of the train.

The Linimo maglev vehicle, at left, and a 100 L vehicle on the test rack, at right.

Element	Typical Characteristics
Vehicle Dimensions	*Length*: 141 ft (triplet) *Width*: 8.5 ft *Height:* 10.5 ft
Vehicle Capacity/ Max. Cruise Speed	*Capacity*: 290 passengers *Cruise Speed*: 60 mph (at 2.7 sq ft per standing pass.)
Consist Sizes	One to two vehicles per train.
Min. Horizontal Turning Radius	164 ft
Empty Vehicle Weight	117,500 pounds on fifteen levitation modules.
Power Source	Third rail
Suspension	Magnetic levitation
Sample Suppliers/ Applications	CHSST "Linimo" Line in Nagoya, Japan

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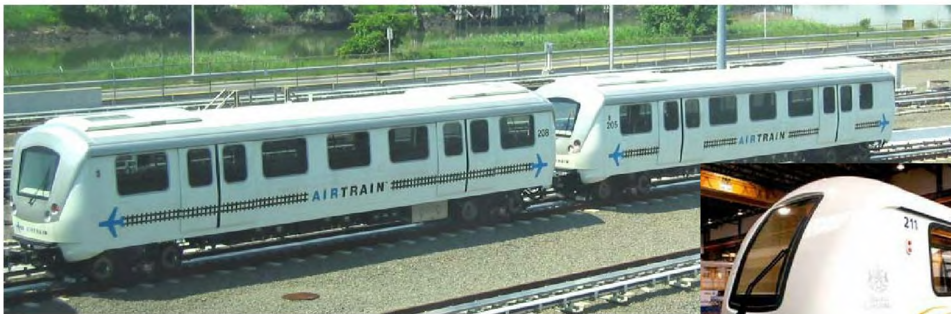
Rapid Rail Vehicle – Medium-sized (Type 1)

Rapid transit vehicles are characterized by large vehicles with steel wheel on steel rail suspension running in an exclusive, separated guideway. The medium-sized, "Type 1", as defined here, is the Bombardier ART MK-II system. This is a proprietary system, but does run on standard gauge rails. This system operates fully automated without drivers and is propelled with Linear Induction Motors (LIM). The stations have level boarding. The Vancouver and Kuala Lumpur vehicles are represented by the lower ends of the ranges shown in the table since those vehicles are smaller than the AirTrain JFK vehicle. The data in the table is for a single car per vehicle to provide ease of comparison with the Type 2 Rapid Rail Vehicle. The existing ART MK II systems actually operate as married pair vehicles although some of the AirTrain JFK vehicles are configured for single car operation. These vehicles rank high in terms of passenger carrying efficiency. The vehicles used on the AirTrain JFK system, since they are wider, have the highest passenger carrying efficiency of all the technologies considered. Type 2, Medium Rapid Transit vehicles and Large Rapid Transit vehicles, however, have higher overall possible capacities since they can be configured into longer trains. The ART II vehicles rank in the moderate range in terms of weight per bearing area.



The AirTrain JFK in New York, New York, above and the SkyTrain in Vancouver, British Columbia, at right.

Element	Typical Characteristics
Car Dimensions	*Length*: 58 ft *Width*: 8.7 to 10.5ft *Height:* 10.8 to 12.5ft
Car Capacity/ Max. Cruise Speed	*Capacity*: 125 to 155 passengers (at 2.7 sq ft per standing pass.) *Cruise Speed*: 50 to 62 mph
Consist Sizes	One to four cars per train for the AirTrain JFK vehicle and one to six cars per train for the Vancouver SkyTrain Line and Kuala Lumpur LRT
Min. Horizontal Turning Radius	164 ft
Empty Vehicle Weight	49,000 to 53,000 pounds on two trucks (two axles per truck).
Power Source	Third rail
Suspension	Steel wheels on steel rails
Sample Suppliers/ Applications	Bombardier: Vancouver SkyTrain, Kuala Lumpur LRT, JFK Airport AirTrain JFK.

Rapid Rail Vehicle – Medium-sized (Type 2)

Rapid transit vehicles are characterized by large vehicles with steel wheel on steel rail suspension running in an exclusive, separated guideway. The medium-sized, "Type 2", as defined here, is the shorter version of rapid transit vehicles that operate in New York (the R-142 design), Chicago, and Boston. They were developed to permit operations along older subway and elevated lines with relatively small radius curves. Rubber-tired applications are not represented although a few systems exist in places such as Montreal, Mexico City, and Paris. The Type 2 vehicles typically operate with drivers, but since they are in exclusive guideway, the system could be automated. They typically have level boarding. Similar to light rail transit, these vehicles can be implemented on any system if they have compatible power collection and train control subsystems. These vehicles rank high in terms of passenger carrying efficiency per unit of length. They also have a relatively high weight per bearing area. The table below represents one car per vehicle, however Bombardier has delivered a relatively new vehicle, the C 20, to Stockholm SL that is lighter, articulated, and shares a total of four bogies among a three-car vehicle. Each car unit is about 50 feet in length, similar to the vehicle lengths for this technology type.

Element	Typical Characteristics
Vehicle Dimensions	*Length*: 45 to 52 ft *Width*: 8.8ft *Height:* 11.9 ft
Vehicle Capacity/ Max. Cruise Speed	*Capacity*: 115 passengers (at 2.7 sq ft per standing pass.) *Cruise Speed*: 50 to 66 mph
Consist Sizes	Four to ten vehicles per train.
Min. Horizontal Turning Radius	90 ft
Empty Vehicle Weight	70,000 pounds on two trucks (two axles per truck).
Power Source	Third rail typically, although applications with OWDS as a second power source (dual power) exist.
Suspension	Steel wheels on steel rails
Sample Suppliers/ Applications	Suppliers: Bombardier, Kawasaki. Applications: NYCT R-142 design in New York, other similar vehicles in Boston on the Blue Line and in Chicago.

Rapid Rail Vehicle – Large-sized

Rapid transit vehicles are characterized by large vehicles with steel wheel on steel rail suspension running in an exclusive, separated guideway. The large-sized vehicles have been used in modern rapid transit projects including the Washington, D.C. Metrorail, Miami Metrorail, Atlanta MARTA, Los Angeles Red Line, and San Francisco BART. The Large-sized vehicles typically operate with drivers, but since they are in exclusive guideway, the system could be automated as is Singapore's North East line. They typically have level boarding. Similar to light rail transit, these vehicles can be implemented on any system if they have compatible power collection and train control subsystems. The table below represents one car per vehicle. These vehicles rank high in terms of passenger carrying efficiency per unit of length. They also have a relatively high weight per bearing area.

The Red Line in Los Angeles, above and the BART system in San Francisco-Oakland, at right.

Element	Typical Characteristics
Vehicle Dimensions	*Length*: 70 to 75 ft *Width*: 10 ft *Height:* 12.0 to 12.5 ft
Vehicle Capacity/ Max. Cruise Speed	*Capacity*: 170 passengers (at 2.7 sq ft per standing pass.) *Cruise Speed*: 55 to 65 mph
Consist Sizes	Two to eight vehicles per train.
Min. Horizontal Turning Radius	145 ft
Empty Vehicle Weight	77,000 to 83,000 pounds on two trucks (two axles per truck).
Power Source	Third rail.
Suspension	Steel wheels on steel rails.
Sample Suppliers/ Applications	Suppliers: Alstom, Bombardier, Kawasaki, Siemens. Applications in U.S.: Atlanta, Baltimore, Boston, Cleveland, Los Angeles, Miami, Philadelphia, San Francisco-Oakland, Washington, D.C.